Slide 1
Dear Colleagues,
Here you can see the title of our joint presentation.

This study was carried out using the Giovanni infrastructure to acquire satellite aerosol data.

We gratefully acknowledge the contribution of our late colleague Dr. Gregory Leptoukh to the creation and implementation of the Giovanni infrastructure.

Slide 2
This slide represents dramatic changes in the Indian population.
You see that, over the last 60 years, the Indian population has increased from ~350 million to ~1.2 billion people.

This significant population growth in the Indian subcontinent has led to water and food shortages.

Moreover, the growing population needs support, such as increasing transportation, fuel consumption for domestic purposes, and industrial development.

All these factors have resulted in increasing anthropogenic aerosol emissions and declining air quality.
Can we detect this declining air quality in the Indian subcontinent?

Yes, we can, by using satellite data.

Slide 3
The relationship between population growth and atmospheric turbidity is not always obvious.
Ramanathan et al. (JGR, 2007) analyzed a possible relationship between population and MODIS AOT in the top 26 megacities around the world. The top panel shows these megacities in the decreasing order of their population in the year 2000. The bottom panel shows AOT over the same megacities.
As you see, there is no correspondence between population figures and AOT.

Let me illustrate this point by comparing Tokyo and Beijing. The population in Tokyo (32 millions) is double the population in Beijing (15 millions). However, the AOT in Beijing (0.64) is double the AOT in Tokyo (0.32).

Slide 4

The study by Ramanathan et al. (2007) included the three largest megacities in India. They are Mumbai, New Delhi, and Calcutta with population 20, 20, and 15 millions; and AOT of 0.39, 0.54, and 0.57 respectively. Again, there is no correspondence between population figures and AOT.

There are many factors which can play a role here, such as air quality regulations in developed and developing countries; aerosol transport; differences in topography and albedo.

Slide 5
This slide represents our resent paper which was aimed at quantifying the effects of urbanization on air quality (characterized by AOT) in the Indian subcontinent.

Slide 6
This is the important point of our approach to estimate the effect of urbanization on AOT.

Slide 7
In order to characterize atmospheric turbidity over the Indian subcontinent, we used 8-y (2000-2008) MODIS and MISR AOT data from the NASA Terra satellite.

Here is a comparison between the 8-y mean distribution of MODIS AOT and that of population density for the post-monsoon and winter season.

You can see even at first glance similarities between the two distributions.

MODIS shows high AOT over the Ganges basin, where population density is high.

MODIS AOT is low over the Himalayas where population density is close to zero.

Slide 8
While trying to obtain a relationship between AOT and population density, we removed the factors which influence AOT, but do not depend on population density.

In the Indian subcontinent, there are three such factors: natural aerosol (desert dust), the effects of cloudiness during the monsoon period; and the anomalous precipitation associated with increased wet removal of atmospheric aerosols.

Slide 9
This slide represents the 8-y mean distribution of MODIS cloud fraction.

You can see that, in summer (monsoon) months, the major part of the Indian subcontinent is characterized by high cloud presence exceeding 0.9 (with the exception of the Thar Desert and northern regions). MODIS and MISR have quite a limited opportunity to view aerosols, if cloud cover is so significant.

Moreover, according to numerous studies by Remer et al., Koren et al,, Zhang et al., when cloud fraction exceeds 0.8, satellite-based AOT is overestimated because of cloud contamination.

Therefore, we considered the monsoon season with high cloud presence to be unsuitable for studying the relationship between population density and satellite-based AOT.

Slide 10

Our analysis of cloudiness and desert dust showed that the period from October to February is the most favorable season for our study of the relationship between urbanization and AOT. This is the season with minimal cloud fraction and minimal dust activity, in accordance with the 8-y average seasonal variation of MODIS cloud fraction, shown in the current slide.

Slide 11

This slide represents the 8-y mean AOT averaged over the regions with differing population densities. As shown in the graphs, there are four regions of differing population density:
1 < PD < 100; 100 < PD < 250; 250 < PD < 500; and PD > 500 persons/km2.

You can observe that the dependence of AOT on population density is monotonic: an increase in population density is accompanied by an increase in AOT. Both sensors (MISR and MODIS) show similar results which support each other.

The rise in average AOT can be attributed to significant aerosol emissions over highly-populated areas, including megacities and main industrial centers.

Slide 12

This slide focuses on the relationship between population growth and AOT trends. This allows us to estimate the deterioration in air quality due to aforementioned dramatic changes in the Indian population.

The graph represents the time series of AOT averaged over four extensive regions with differing population densities.
Our analysis of these time series of AOT showed the following:
a) For highly-populated regions with population density PD > 100 persons/km2 (the red, black, and green lines), the population growth of ~1.5 %/year was accompanied by an increasing AOT

trend of over 2 %/year.
b) Over sparsely-populated territories in the Indian subcontinent (the blue line), there was no statistically-significant trend. This indicates that these territories are distant from anthropogenic air-pollution sources.

Slide 13
It is interesting to compare our results with those of Ramanathan et al. (2007).
You can see that when we use the averaging of AOT over the extensive territories, we were able to obtain a monotonic relationship between AOT and population density.

By contrast, as shown by Ramanathan et al (2007), there was no correspondence between AOT and population figures for separate megacities. That is why they concluded that population figures are not a good proxy for anthropogenic aerosol emissions.

Conversely, we conclude that population density can be used as a proxy for anthropogenic aerosol emissions in the Indian subcontinent, if AOT is averaged over the extensive territories with differing population density.

Slide 14
These are our conclusions:

Over the specified regions in the Indian subcontinent with differing population densities:
a) the higher the averaged population density – the bigger the averaged AOT,
b) over more than 70% of the Indian subcontinent, a population growth of ~1.5% year was accompanied by increasing AOT trends of over 2% year.

Thank you for the possibility to attend this Workshop.

James Acker:
Any questions? We are on schedule.

Dimitris Kaskaoutis:
one comments from me, please

I know that article by Pavel

I want to note that this very good correlation between population density and AOD can be partly attributed to the topography of the Ganges valley

more specifically, since the study is limited in post-monsoon and winter periods
(and this was well done)

the most of aerosols are accumulated in the lower Ganges basin (eastern parts) in Bihar
and west Bengal states

these areas are also the most densely populated in India

so, we may have also this in mind in discussing these results

another obviously difficulty in assessing the correlations during post-monsoon season is....

the large AODs over northwestern Indo-gangetic Plains, in Punjab state where crop residue burning takes place each October and November, thus enhancing the AODs over an area not being so densely populated

that's my comments

James Acker:
Thank you. Anyone else?